ENGINEERING AND DESIGN - TAUTOLOGY OR OXYMORON?

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Abstract
Misunderstandings are prevalent amongst students, teachers and the wider community about the scope of technology education, design, the engineering profession and what engineers actually do. I was shocked when questions were asked by teachers about the suitability of engineering graduates to teach in the Technology and Applied Studies area in schools because 'they have no design in their degree'. This paper aims to clarify these misunderstandings about the nature of engineering and engineering design. In doing so it will better inform educators and students in schools about the technical resources and expertise available from the engineering profession to support technology education. The findings of investigations into the links between engineering, design process, and technology education are presented. I conclude that professional engineers are involved in design process in real-life situations. I also conclude that it is important that engineering graduates are involved in teaching in High Schools to better inform students (and their teachers) about engineering. Without the engineering perspective of design process in technology education, the depth of understanding of both design and engineering remains superficial and unbalanced.

Introduction
Is technology education beyond Information Technology (IT)? While an education in IT, both hardware and software is essential in today’s world, technology and technology education must be recognised in its broadest sense. Technology education K-12 is the grounding our students have that leads to many career paths, including engineering – of particular interest to me.

I was shocked when questions were raised recently by teachers in decision-making positions about the suitability of engineering graduates to be trained to teach in the TAS area in schools because 'they have no design in their degree'. From my experiences teaching in the Technology and Applied Studies (TAS) learning area in secondary schools in NSW, in the Graduate Diploma of Education (TAS) in three universities and lecturing in the Faculty of Engineering at the University of Technology Sydney (UTS) I know this to be incorrect. Misunderstandings like this, about the scope of the engineering profession and what engineers actually do, are prevalent amongst school students, teachers and the wider community. To clarify the issue it was clearly necessary to assess and document how suitable engineers are to train as teachers in the Technology and Applied Studies area.

Engineering and design
To understand how design process, engineering, and technology education (in its broadest sense) are linked we need to consider these questions:
• What is the syllabus definition of ‘design’?
• Are engineers involved in designing?
• Do engineers use a design process?

The implications of the answers to these questions are not fully understood by many of the players or stakeholders in design, engineering, and technology education. This paper
aims to clarify misunderstandings about the nature of engineering and engineering design to better inform technology educators and students in schools about the technical resources and expertise available from engineers. In turn, this understanding will help inform decisions made by school students about career choices, teachers who guide students in these choices, and those training and selecting suitable graduates to train as teachers in the TAS learning area in schools.

**Syllabus definitions of ‘design’**
The NSW syllabus for Stage 4 and 5 (N.S.W. Board of Studies 1992) gives an overview of the outcomes of students whilst working through a design process. These outcomes include analysing a need, investigating, generating ideas, testing, making decisions and choices, evaluating and reflecting, making, and managing.

**Are engineers involved in designing?**
To answer this question we can examine current:
- **subjects** taken by engineering students at universities, specifically at the University of Technology Sydney (UTS)
- **textbooks and journals** that support engineering education
- **studies** from the engineering workplace
- **accreditation criteria** used by the Institution of Engineers Australia for engineering courses and engineers

**Subjects from UTS Engineering**
The process of design is explicitly taught through a variety of subjects both in the Core Program and specific Field of Practice subjects at UTS. Subject descriptions from the UTS Engineering Handbook (UTS 2001) show that not only is design process (sometimes referred to as Engineering Method) taught, but is also used in actual design projects. In fact ‘design’ is significant enough to be mentioned in short descriptions of at least 14 subjects. Dimensions of ethics, sustainability, appropriate technology, social and historical contexts are also explicit in the teaching program. The rigour of Engineering Science is also addressed.

My involvement in some of these subjects has provided me with evidence that this is not only rhetoric but explicit practice. Examination of the assessment tasks of many subjects also demonstrates this, as does an examination of the outcomes of the final year Capstone Project and the graduate attributes expected of our students (available from UTS Engineering).

**Textbooks and journals that support engineering education**
Textbooks used to support engineering courses, both in Australia and overseas, put a significant emphasis on the importance of understanding and using design process effectively. This process is often described as 'Engineering Method', not to be confused with 'Scientific Method' also used by engineers and scientists.

Holtzapple & Reece (2000), in their first chapter, distinguish between the goals of scientists and engineers. The authors describe the ‘engineering method’ briefly as:
- ‘Identify and define the problem
- ‘Assemble a design team
- ‘Identify constraints and criteria for success
- ‘Search for solutions
• Analyze each potential solution
• Choose the ‘best’ solution
• Document the solution
• Communicate the solution to management
• Construct the solution
• Verify and evaluate the performance of the solution

In a later chapter on design these same authors expand on the engineering method showing it to be equivalent to the process of design outlined in the Design and Technology mandatory and elective syllabuses of NSW at both Primary and Secondary school levels (N.S.W. Board of Studies, 1991, 1992, 2000). In Holtzapple & Reece’s exercise on designing an improved paper clip, the authors further describe and use the process of design in detail, using it in a real-life project example.

Most current engineering textbooks that support first year students have an early chapter outlining the design process (engineering method, software development process). Even texts about topics more removed from engineering design see design process as a major issue for engineers (Johnston et al 1999).

The Australasian Association for Engineering Education conference proceedings and journals have many papers about design education for engineers. One such paper from staff in the Faculty of Engineering at Queensland University of Technology (Heldt & Black 1997) describes how their courses allow students to learn design by explicit involvement in design process to meet real needs.

There are entire books published on Engineering Design and Engineering Method (Birmingham et al, 1997; Pugh 1991; Ullman 1997; Lewis & Samuel 1989; Field 1997). In the description of ‘design’, given early in their book on Engineering Design, Lewis and Samuel (1989) use steps, familiar to technology educators in schools, like recognize problem, define problem, search for alternative proposals, predict outcomes, test for feasible alternatives, evaluate feasible alternatives, implement solution, meet needs. These terms are similar to those used in the design process taught in NSW schools.

Studies from the engineering workplace
I have interviewed seven engineers who have worked or are currently working in their field of engineering practice. I also searched print and web-based materials about engineers and their work.

One engineer interviewed saw engineering design as:
‘... often characterised by a haphazard process of first ‘thinking’ of a solution, then analysing it against the design criteria, then iterating it and analysing it again. The process is repeated until a good enough solution is found. This can often lead to sub-optimum solutions, or no solution at all. In essence, one needs a formal procedure that ‘touches all bases’ or comprehensively tries all the possibilities.’ (Braun 1999)

Another engineer interviewed stated that:
‘the precepts of design, in which reflection, judgement and consideration of the context are essential elements to the solution of engineering problems...’ (Marks 1999)
Petroski (1992) points out that:

‘The idea of design … is central to engineering, and I take design and engineering to be virtually synonymous … To understand what engineering is and what engineers do is to understand how engineering failures can happen and how they can contribute more than successes to advance technology.’

In his chapter ‘Design is getting from here to there’, Petroski describes the seemingly haphazard process of designing; the ways in which prior experience, historical and social contexts and failure can determine the design direction. To clarify some of the complexities of the process of designing a bridge, he likens the process to designing a holiday trip. This is the rationale behind making Design and Technology mandatory in Years 7-10. By designing simple things using a design process our students can mature to become better problem solvers in real-life design situations.

In the website developed within days of the terrorist attack on the World Trade Centre towers in New York (University of Sydney – Department of Civil Engineering, 2001) there is no doubt in the writing of the engineers that engineering design was as important as the architectural design of the buildings.

‘Unique to the engineering design were its core and elevator system. The twin towers were the first supertall buildings designed without any masonry. Worried that the intense air pressure created by the buildings’ high speed elevators might buckle conventional shafts, engineers designed a solution using a drywall system fixed to the reinforced steel core.’

Architects collaborate with engineers so that both can design together. Without one the other produces an inferior or impossible product. An example of this collaboration that is closer to home is seen in the final design of our Sydney Opera House where engineers worked with the ideas of the architect to design a building that was possible and safe.

**Accreditation criteria used by the Institution of Engineers Australia for engineering courses and engineers**

In consultation with its members, employers of engineers, key industry groups and other interested parties, the Institution of Engineers, Australia (IEAust) (Institution of Engineers Australia 1999) has produced a set of National Generic Competency Standards for engineers to ensure that they perform at a standard consistent with World Best Practice. These standards:

- are the foundation for the assessment for eligibility and registration of an engineer
- are an aid in the design of undergraduate and postgraduate courses in engineering
- provide the benchmark for the evaluation of overseas qualifications and experience for recognition in Australia.

One core competency listed in these standards as mandatory for all engineers is ‘Engineering planning and design’. Some elements of the design process outlined in the full description of this competency unit include:

- negotiates and interprets the client’s requirements
- … implications for sustainability
- selects and applies engineering standards
- seeks advice from appropriate personnel and sources
- collaborates with the client
- … impacts on the community
- seeks advice on latest technologies
• implements planning and design process
• prepares and maintains documentation during the design process

There is no doubt that the meaning of design and design process used by the IEAust is comparable with that used by the NSW syllabuses (N.S.W. Board of Studies, 1991, 1992, 2000). This can be seen by the definitions supplied in the Range Statement of the IEAust standards:

‘Design requires the consideration and identification of a problem or opportunity to improve an existing design. Design is the conceptual process used to bring together innovation, aesthetics, and functionality to plan and create an artefact, a product, a process or a system to meet an artistic or industrial requirement of an individual or group. The design process achieves an engineering solution…Design also includes engineering planning … taking into account all the factors affecting their relationship and their inter-relationships with the external environment.’ (Institution of Engineers Australia, 1999)

The underpinning knowledge and skills required to meet this competency unit include:

• knowledge of:
  • design principles for the relevant area of engineering technology
  • understanding of the imperative for sustainability and environmental impacts
  • relevant engineering standards
  • Occupational Health and Safety requirements

• and skills of:
  • problem-solving
  • communication and consultation
  • presentation and reporting

All these features are also listed as requirements in the NSW Technology and Design syllabuses.

Do engineers use a design process?
It can be seen from the findings documented above that engineers are explicitly taught and are required to practice ‘design’ and ‘design process’. All engineers interviewed for the studies above, when asked to describe the process they used, gave a list of steps that included defining the problem, generating multiple ideas, evaluating and assessing, making choices based on evaluations, compliance with criteria for success, specifications and safety requirements… Many also noted that this process was iterative’, ‘circular’, ‘going round in circles’. It was found that, like all ‘designers’ (including architects, industrial designers, clothing designers, web designers and more), engineers do not always follow just one strict linear design process but rather weave in and out of the steps described by Holtzapple & Reece (2000). However, this ‘weaving’ is not haphazard, but directed by constraints, analysis, specifications, development of new ideas and even the ‘ahha’ factor.

Many engineers have described the engineering design process as flow charts. Like the teacher’s view of design process none of them are linear, all of them are iterative. Some of these include those mentioned earlier (Birmingham et al, 1997; Pugh 1991; Ullman 1997; Johnston et al 1999; Lewis & Samuel 1989; Field 1997). Many of these flow
charts have similarities to those TAS teachers are encouraged to teach (Jacobs 1997, 1998).

At an American Society of Mechanical Engineers Design Conference, Lienhard (1995) discussed current shortfalls and his vision of engineering design and engineering design process. Building on his belief that ‘You cannot be an engineer without designing’ he discusses three important ingredients for success in engineering design
- trial and error … the courage to make mistakes
- co-operation … designers cannot work in isolation
- visualisation … we must see things through new eyes without just relying on computer modelling of designs.

Are today’s engineers equipped to teach in the TAS learning area?
Answering this question must be based on sound examination of both prior knowledge and teacher training. However, the discussion above demonstrates that ‘they have no design in their degree’ is clearly erroneous. Inherent in technology education is the need for educators and students to have technical knowledge to support their designing and to have teachers trained and practiced in using design process. These are two important features that link engineering and technology education. We must understand that:
- engineers practice design. They have design process as an integral part of their education and work practices in both implicit and explicit forms
- technology educators and designers need the technical knowledge that engineers are able to offer if they are to create designs that work and are safe.

There are two types of support engineers can offer technology education:
- supporting classroom teaching and curriculum development with technical knowledge
- becoming teachers in the Technology and Applied Studies learning areas by training through graduate programs and/or combined degrees.

Technical support for technology education
Elsewhere (Jacobs 2000) I have outlined the need design educators have for technological expertise and/or mentors to support their technology education. The Faculty of Engineering at UTS has supported the EngineeringLinks initiative to provide this service by tapping into the learning and experience of its more advanced undergraduate engineering students. EngineeringLinks is a project run within an elective subject (Professional Service Project) for engineering students and is a service for educators and school students. More about this project can be found on the website www.eng.uts.edu.au/links.

 Engineering students and staff from all fields of practice work in the EngineeringLinks program to:
- present engineering to Years 6-12 students
- provide mentors to a variety of educators and their students
- maintain a website that is continually updated to provide web-based resources for educators and their students
- develop opportunities for educators, their classes and individual students to visit the laboratory displays, lectures and demonstrations in the faculty

Technology challenges in the form of mini design projects, an Engineering Discovery Day and an EngineeringLinks Expo are ‘hands-on’ developments of the program. Print-
based resources to meet syllabus needs have also been developed. The program is very flexible and outcomes are negotiated with each educator involved.

The IEAust in its **Neighbourhood Engineers** program provides another opportunity for technology and design educators to develop links with engineers. Through this program, practicing engineers are linked to one or more schools to provide contact for students and their teachers with an engineer.

These are just two of the possible ways that teachers and curriculum developers can access the expertise of engineers to support technology education.

**Teacher training for technology education**

In making decisions about appropriate education for teachers in the Technology and Applied Studies learning area consideration of explicit and implicit involvement in design process is essential as design is and must continue to be a significant feature of this learning area.

Inherent in these processes of design are the dimensions that include ethics, sustainability, appropriate technology, social and historical contexts and the ability to find relevant technical support and mentoring when required. Teachers cannot know everything, but with a good understanding of design process and its inherent dimensions and problem-solving strategies, technology teachers can guide students through fulfilling and meaningful design projects that develop life-long skills and meet real needs.

In fact, it is important that engineering graduates are involved in teaching in schools to better inform students (and their teachers) about the engineering dimension of design process and to encourage them into the profession. While ‘engineers don’t teach and teachers don’t engineer’ (Jacobs 2000) misconceptions like the one on which this paper is based will continue and career paths into engineering will be closed through ignorance.

**Conclusion**

Engineering and technology education are linked by their common threads of design process, technological understanding and consideration of the contexts and issues involved in designing and using technology. By understanding and creating links, engineers can develop their communication with the people they serve and technology educators can develop relationships with engineers who can support their teaching strategies and curriculum development.

Teacher training for technology and design education should draw from those who have prior knowledge and skills in designing, technological understanding and consideration of the contexts and issues involved in designing and using technology and should include further development of these in their training programs. Engineering graduates from UTS clearly have these knowledge, skills and understandings in their training.

From the findings of investigations into the links between engineering, design process, and technology education, I conclude that engineers are involved in design process in real-life situations. I also conclude that it is important that engineering graduates are involved in teaching in High Schools to better inform students (and other teachers)
about engineering. Without the engineering perspective of design process in technology education, the depth of understanding of design, technology and engineering remains superficial and unbalanced.

Yes! Technology education must be beyond IT!

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